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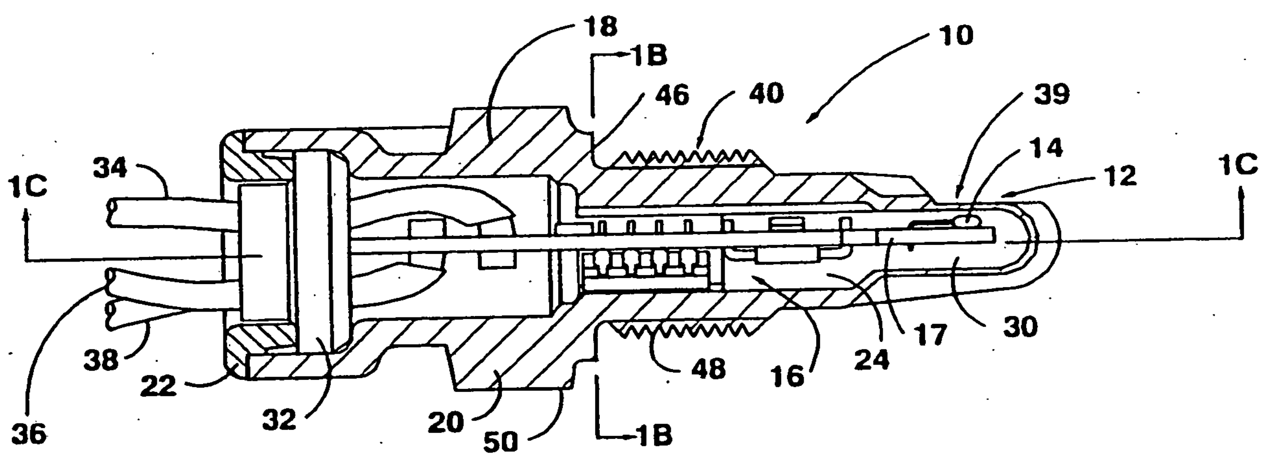
(54) Title: ACTIVE COOLANT TEMPERATURE SENSOR IN A NON-METAL HOUSING



(57) Abstract

A temperature sensing apparatus (10) is provided which includes a temperature sensitive device (12) having an electrical resistivity which varies with temperature. A conditioning circuit (16) is electrically connected to the temperature sensitive device (12) and adapted to measure a resistance across the device and produce an electrical signal which is insensitive to external resistive loading and which is responsive to the sensed resistance. The apparatus (10) also includes a non-metallic, liquid resistant and thermally conductive housing (18) encapsulating the temperature sensitive device (12) and the conditioning circuit (16). At least one electrical conductor (38) is connected to the conditioning circuit (16) and adapted to transmit the signal output from the conditioning circuit (16). The conductor (38) extends through the housing (18) for electrical connection to circuitry external to the housing (18).

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Description

Active Coolant Temperature Sensor In A Non-Metal Housing

Technical Field

This invention relates generally to a temperature sensor which is adapted to provide an electrical indication of a sensed temperature and, more particularly, to a coolant sensor having a sensing element and conditioning circuit packaged in a non-metallic housing.

Background Art

Temperature sensors have numerous applications such as engine coolant sensors in the automobiles. Traditionally, most sensors have taken the form sensing elements such as thermostats having switched outputs. However, with the advent of complex electronic engine controllers, it is desirable to provide an absolute indication of the sensed temperature rather than merely a switched output.

Hence, modern sensors typically incorporate passive devices such as thermistors, negative thermal coefficient devices (NTC) or positive thermal coefficient devices (PTC). The output of these passive devices is typically in the form of a resistance which varies with temperature. Extreme conditions such as water, thermal cycle, and vibration can lead to a degradation of the wiring harness used to connect the sensor to the engine controller. For example, moisture can induce conductivity between individual wires in the wiring harness and over time the resistance of the individual wires can change. Such wiring harness degradation can induce

inaccuracies in the signal received by the engine controller.

Past sensors suffer from further disadvantages because they are typically constructed with metal housings. Known devices involve fitting the sensing element into a housing constructed of brass or other similar metals. The housing typically includes an exterior thread and a hexagonal portion enabling the device to be screwed into a reciprocal threaded aperture in an engine block, for example. Sensing devices having metal housings are disadvantageous because of the relatively high costs associated with machining parts and the time-intensive assembly process. A further significant disadvantage of metal housings, and particularly those formed with a hexagonal nut portion, is that the metal acts as a heat sink and draws the heat away from the sensing element, thereby causing inaccurate temperature readings.

In response to the problems associated with metal housings, it is known to construct a sensing device of molded plastic housings. United States Pat. No. 4,548,780 discloses three embodiments of a temperature sensor having a housing which is formed, at least in part, by using injection molded plastic. However Patent No. 4,548,780 only discloses the use of passive devices which, as mentioned above, are inaccurate due to wiring harness degradation and external resistive loading. Therefore, it is desirable to provide a sensing device which has a sensing element and active electronics for "driving" an output onto a wiring harness contained within a single housing. However, it is not practical to use an injection molding process as disclosed in '780 because the active electronics would be damaged by the

temperatures required for injection molding. It could be possible to develop a sensor having active electronics contained in a metal housing; however, such a sensor would still suffer from the disadvantages associated with metal housings.

The present invention is directed to addressing the above mentioned problems with a sensor having the advantages of a plastic housing and self-contained active electronics for driving an output signal onto a wiring harness.

Disclosure of the Invention

A temperature sensing apparatus is provided which includes a temperature sensitive device having an electrical resistivity which varies with temperature. An conditioning circuit is electrically connected to the temperature sensitive device and adapted to measure a resistance across the device and produce an electrical signal which is insensitive to external resistive loading and which is responsive to the sensed resistance. The apparatus also includes a non-metallic, liquid resistant and thermally conductive housing which encapsulates the temperature sensitive device and the conditioning circuit. At least one electrical conductor is connected to the conditioning circuit and adapted to transmit the signal output from the conditioning circuit. The conductor extends through the housing for electrical connection to circuitry external to the housing.

Also disclosed is a method of manufacturing a temperature sensor which involves mounting a temperature sensitive device on a circuit board, the temperature sensitive device having a resistivity which varies with temperature; mounting a conditioning circuit on the circuit board, the conditioning circuit

being electrically connected to the temperature sensitive device and adapted to sense the resistivity of the temperature sensitive device and produce an electrical signal which is insensitive to external resistive loading and whose magnitude is responsive to the sensed resistance; injection molding a housing from non-metallic water resistant and thermally conductive material, the housing having an internal cavity for receiving the circuit board; connecting at least one electrical conductor to the conditioning circuit, the conductor being adapted to transmit the conditioning circuit output signal to circuitry external to housing; inserting the circuit board into the housing cavity; and sealing the housing cavity to isolate the circuit board from the atmosphere.

Brief Description of the Drawings

Fig. 1A is a diagrammatic sectional view of the present temperature sensor;

Fig 1B is a cross-section view of the sensor housing along line B-B of Fig. 1A;

Fig. 1C is a cross-sectional view of the present temperature sensor along line C-C of Fig. 1A;

Fig. 2 is a circuit diagram of a first embodiment of the present temperature sensor; and

Fig. 3 is a functional block diagram of a second embodiment of the present temperature sensor.

Best Mode for Carrying Out the Invention

Referring now to the drawings, the present temperature sensor 10 will be described. The sensor 10 will be described as an engine coolant temperature sensor; however, it should be understood that the principles described herein could be applied to

numerous other applications where there is a need to sense the temperature.

The temperature sensor 10 includes a temperature sensitive device 12 having a parameter which varies with temperature. Preferably, the device 12 is in the form of a thermistor 14 having an electrical resistance which varies with temperature. However, it should be understood that other suitable devices such as an NTC device, a PTC device, a thermocouple or a semiconductor device could be used to perform the function of the temperature sensitive device 12 without departing from the scope of the invention. The temperature sensor 10 further includes a conditioning circuit 16 which is electrically connected to the temperature sensitive device 12. The conditioning circuit 16 is adapted to measure a resistance across the device 12 and produce an electrical signal which is insensitive to external resistive loading and which has a magnitude responsive to the sensed resistivity. The conditioning circuit 16 will be described in greater detail below in connection with Figs. 2 and 3. The conditioning circuit 16 and thermistor 14 are surface mounted on a circuit board 17 for convenient assembly. The electronics 14,16 have been mounted on the circuit board 17 using known practices in a manner which minimizes the board size and maximizes rejection of electromagnetic interference (EMI). The circuit board layout coupled with the use of ferrite inductors enables the sensor to operate correctly in field strengths of 100 V/m from 15 KHz to 1 GHz.

The temperature sensor 10 further includes a non-metallic, liquid resistant and thermally conductive housing 18 which encapsulates the circuit board 17, the temperature sensitive device 12 and the

conditioning circuit 16. The housing 18 includes a main body portion 20 and an integrally connectable cap portion 22. The entire housing 18 is formed by injection molding a composition of polyethersulfone and between 20 and 45 percent glass fiber. Other fiber materials such a graphite fiber may be substituted for the glass fiber, as would be apparent to one skilled in the art. The percentage of fiber is selected based on the housing design and desired housing characteristics, and in the present application, the housing contains between 28 and 33 percent fiber material. In the case of a coolant sensor, the main design criteria is that the housing 18 provide adequate chemical resistance to ethylene-glycol mixtures which are used in engine coolants. Hence, other materials having the characteristics of polyehtersulphone, such as polyetherimide, may also be used to form the housing 18. However, materials such as nylon and polyphthalamid which are permeable by waterbased engine coolants are not suitable for the housing 18 because such materials allow moisture to infiltrate the housing 18 and damage the conditioning circuit 16.

The housing 18 has an internal cavity portion 24 which is configured to receive the circuit board 17. During assembly, the circuit board 17 is inserted into the housing cavity portion 24. To facilitate more rapid assembly, the housing cavity portion has first and second grooves 26a, 26b (See Fig. 1B) which are adapted to receive the printed circuit board 17. Moreover, the circuit board 17 includes beveled edges 28a, 28b (See Fig. 1C) which help guide the circuit board 17 into the grooves 26a, 26b during assembly.

Prior to assembly, the predetermined amount of potting material 30 is injected into the housing cavity portion 24. A "soft" potting material such as 1265 Eccogel as manufactured by Emerson Cummings. Silicone gel or epoxy gel are also suitable potting materials. It is critical that a "soft" potting material is used because a "hard" potting can crack or damage the surface mounted electronics during the thermal cycling. Additionally, a "hard" potting could cause stresses on the housing during thermal cycling. Insertion of the circuit board 17 into the cavity portion 24 forces the potting material 30 around the electronic components 14, 16. The potting material 30 serves to restrict movement of the electronics 14, 16 during vibration and consequently reduces vibration related problems. The potting material 30 also facilitates heat transfer between the sensed medium and the thermistor 14. Conversely, if the cavity portion 24 was left as an air gap, the air would act as an insulator and increase the sensor's 10 response time.

A compression grommet 32 constructed of rubber or other like material is inserted in the cavity 24 behind the circuit board 17. The compression grommet 32 is constructed so as to conform to the cavity's configuration and form a seal against moisture infiltration. The grommet 32 is held in compression by the cap portion 22 which bonded to the body portion 20 after the grommet 32 is inserted into the cavity portion 24. It is foreseeable that the housing cap and main body portions 20, 22 could be secured using a bonding material such as epoxy or an adhesive; however, the two parts are preferably connected using ultrasonic welding. This process insures a complete and permanent connection between

the two parts and is easy to use in a manufacturing environment.

At least one electrical connector extends through the rubber grommet 32 for connecting the conditioning circuit 16 to an external electrical circuit (not shown) such as an engine controller. In the preferred embodiment, three electrical conductors are provided. A first electrical conductor 34 supplies a preselected voltage potential to the sensor 10. A second electrical conductor 36 is connected to system ground. The third electrical conductor 38 is connected to the conditioning circuit 16 for transmitting the sensor output signal to external electrical circuitry. The conductors 34, 36, 38 have been illustrated as insulated copper wiring; however, the conductors 34, 36, 38 could also be embodied in electrical terminals without departing from the scope of the present invention.

The conductors 34, 36, 38 extend through individual apertures (not shown) in the rubber grommet 34. The apertures are constructed to be smaller in diameter than the outside diameter of the conductors 34, 46, 38, thereby insuring proper seal against moisture infiltration. During assembly, the conductors 34, 36, 38 are inserted through the apertures and connected to the circuit board. The grommet and circuit board 17 are then inserted into the cavity portion 24 simultaneously. Prior to insertion, the grommet 32 position is adjusted by sliding the grommet 32 along the conductors 34,36,38 so that further adjustment is not required after insertion. The cap portion 22 is then bonded to the main body portion 20 as set forth above. Compression of the grommet 32 during this step prevents moisture

infiltration through the apertures and between the gromm t 32 and housing 18.

The housing 18 has several other important features which should be noted. First, the housing 18 includes a thermal conducting portion 39 which is in close proximity with the temperature sensitive device 12. As can be seen from the drawings, the housing is relatively thin in the thermal conducting portion 39, thereby enabling the temperature sensitive device 12 rapidly detect temperature changes in the medium to which the sensor 10 is exposed. The housing thickness in the thermal conducting portion 39 has been empirically determined to provide optimal thermal response and still meet minimum strength requirements as set by design specifications. The minimum thickness is limited by the molding process and selected material, as would be apparent to one skilled in the art. Presently, in housings constructed of polyethersulfone, the housing thickness in the thermal conducting region 39 is specified to be .018 inches.

In the case of an engine coolant sensor, the housing 18 is formed and configured so as to be received into an aperture (not shown) of an engine block (not shown). Once the sensor 19 is positioned in the aperture, the thermal conducting portion 39, and hence the temperature sensitive device 12, is in thermal communication with the interior of the aperture for sensing a temperature therein. The electrical conductors 34,36,38 extend outside the aperture for electrical connection to circuitry external to the aperture. For this purpose, the housing 18 includes a cylindrical portion 40 which terminates in a shoulder portion 46. The shoulder portion 46 is configured to be larger in diameter than the aperture (not shown). The housing 18 extends into

the aperture to a depth which is controlled by the shoulder portion 42. To ensure a proper seal, a rubber O-Ring (not shown) should be placed between the shoulder portion 42 and the engine block.

In some applications, it may be desirable to threadably engage the sensor 10 into a reciprocal threaded aperture. In such applications, the cylindrical portion 40 includes a threaded exterior portion 48. The threaded exterior portion 48 allows the housing 18 to be screwed into a reciprocal threaded aperture in the engine block (not shown). The housing 18 also includes a hexagonal portion 50 which allows the housing 18 to be screwed into the aperture with sufficient torque to prevent fluid leakage and loosening due to vibration.

In other applications, it may be desirable to eliminate the threaded portion 48 and form the cylindrical portion 40 with a smooth outer surface (not shown). In such an application, the depth to which the sensor 10 is inserted into the aperture could be controlled by the shoulder portion 46. A proper seal can be achieved by ensuring that the smooth outer surface has a diameter which requires that the housing 18 be forceably fit into the aperture or through the use of an O-Ring seal.

Referring now to Fig. 2, a first embodiment of an electrical circuit for practicing the immediate temperature sensor 10 will be described. A first terminal 52 of the thermistor 14 is connected to the first electrical conductor 34 through an inductive filter 54 for receiving the preselected voltage potential V_S. The inductive filter 54 is provided to filter out electromagnetic interference (EMI) and radio frequency interference (RFI). A second terminal 56 of the thermistor 14 is connected to system ground

through a first capacitor 58. As was discussed above, the thermistor 14 is positioned on the circuit board 17 so as to be in close proximity with the thermal conducting region 39 when the circuit board 17 is inserted into the housing 18.

The resistance between the thermistor first and second terminals 52, 56 changes as a function of the sensed temperature. A conditioning circuit 60 is provided for sensing the resistance across the thermistor 14 and producing an output signal which is insensitive to external resistive loading and is responsive to the sensed resistance. The conditioning circuit includes a voltage divider network 60 which is adapted to sense the resistance across the thermistor 14 and responsively produce a signal having a voltage which is proportional to the sensed resistance. The voltage divider network 60 includes first and second resistors 64, 66 serially connected between the preselected voltage potential V_S and system ground. Moreover, the thermistor 14 is electrically connected in parallel with the first resistor 64. Hence the voltage drop across the first resistor 64 is proportional to the resistance of the thermistor 14.

The junction of the first and second resistors 64, 66 is connected to a non-inverting input terminal of an operational amplifier (op-amp) 68 for receiving the output voltage of the voltage divider network 60. An inverting input terminal of the op-amp 68 is connected to an output terminal of the op-amp through a voltage follower circuit 70. The op-amp 68 is a "rail-to-rail" CMOS op-amp. This is significant because, ordinary op-amps require 1.5 volt typical headroom (i.e., maximum output = $V_S - 1.5$) which reduces sensor resolution when a small supply voltage V_S is utilized. The voltage follower circuit 70

includes a second capacitor 72 connected between the op-amp output terminal and system ground. A third capacitor 74 is connected between the op-amp inverting input terminal and system ground. The follower circuit 70 further includes a third resistor 76 connected between the op-amp inverting input terminal and the op-amp output terminal. The op-amp output terminal is connected to the third electrical conductor 38 through a second inductive filter 77.

The op-amp 68 produces an output signal which has a magnitude proportional to the temperature sensed by the thermistor 14 and which is insensitive to the problems associated with wiring harness degradation. Specifically, the op-amp 68 provides an output signal having sufficient current to overcome resistive wiring harness loading. Moreover, the inductive filters 54, 77 reduce the problems associated with EMI and RFI. Finally, the "active" conditioning circuit 60 is advantageous over passive sensors because the controller can readily be programmed to detect faulty operating conditions in the sensor. For example, if the signal line in a passive sensor is cut, the resistance of the wiring could be interpreted as a valid temperature signal. Moreover, even if the wire is not cut, significant resistive loading on the wiring harness could adversely affect sensor's output by shunting out the sensor's resistance. However, the conditioning circuit 60 of the first embodiment operates in a predefined voltage range and a controller can easily be programmed to interpret out of range voltages as faults.

Referring now to Fig. 3, a second embodiment of the conditioning circuit will be discussed. Like components in the first and second embodiments have

been given the same element numbers and will not be discussed in further detail. In the second embodiment, the conditioning circuit 16 is adapted to produce a pulse-width-modulated output signal having a constant frequency and a duty cycle responsive to the sensed temperature.

The conditioning circuit 16 includes the voltage divider 62, a square wave generator 78, an integrator 80 and a comparator 82. The square wave generator 78 has an input terminal 84 connected to the first electrical conductor 34 and adapted to receive the preselected voltage potential V_S. The square wave generator 80 responsively produces a square wave signal having a predetermined amplitude and base frequency, as is common in the art. An input terminal 86 of the integrator is connected to an output terminal 88 of the square wave generator 78 and adapted to receive the square wave signal. The integrator 80 integrates the square wave signal and responsively produces a sawtooth waveform signal having a predetermined amplitude and base frequency, as is common in the art. An output terminal 90 of the integrator 80 is connected to a non-inverting input terminal of the comparator 82 for delivering the square wave signal. The comparator 82 further has an inverting input terminal connected to the first and second resistors 64, 66 and being adapted to receive the voltage divider output signal. A fourth capacitor is connected between the comparator output terminal and the comparator non-inverting input terminal to provide AC hysterisis for noise immunity. The comparator 84 produces a signal at its output terminal in response to the voltage divider output and sawtooth waveform signals. More particularly, the comparator 82 produces a pulse-width-modulated (PWM) signal

having a constant frequency and a duty factor responsive to the magnitude of the voltage divider output signal and thus the sensed temperature. A pull-up resistor is connected between the comparator output terminal and a preselected voltage potential V_1. The pull-up resistor 94 biases the output terminal of the comparator 82 "high" whenever it is not internally pulled "low."

Industrial Applicability

The primary application of this invention is felt to lie in the automobile industry, but it is likely that many other applications exist where a sensing device is required to be mounted in an aperture for sensing the temperature inside the aperture. In the automotive industry, a prime use of the immediate invention arises from the need to sense the coolant temperature of an internal combustion engine. In such an application, the housing can be configured having either a smooth or threaded exterior portion depending on design criteria. The sensor 10 is inserted into a reciprocal aperture in the engine block such that the thermal conducting portion 39 of the sensor 10 is disposed in the engine coolant. The housing 18 is formed of a composition of polyethersulfone, or other like material, and glass fiber.

Once in place, the sensor 10 operates to produce an electrical signal which is responsive to the sensed coolant temperature and is insensitive to external resistive loading. This is accomplished by providing a conditioning circuit 16 which senses the resistance of the thermistor and "drives" an electrical output onto the third conductor 38. The third conductor 38 is in turn connected to an external

electrical circuit, such as an engine controller, which utilizes the output signal for further processing.

Other aspects, advantages and objects can be obtained from a study of the drawings, the disclosure and the appended claims. While the present invention is described for use as a coolant sensor it is recognized that such an apparatus could be adapted for numerous other temperature sensing applications.

Claims

1. A temperature sensing apparatus (10), comprising:

a temperature sensitive device (12) having an resistance which varies with temperature;

a conditioning circuit (16) being electrically connected to the temperature sensitive device (12) and adapted to measure a resistance across the device and produce an electrical signal which is insensitive to external resistive loading and which has a magnitude responsive to the sensed resistance;

a non-metallic, liquid resistant and thermally conductive housing (18) encapsulating the temperature sensitive device (12) and the conditioning circuit (16); and

at least one electrical conductor (38) being connected to the conditioning circuit (16) and adapted to transmit the signal output from the conditioning circuit (16), the conductor (36) extending through the housing (18) for electrical connection to circuitry external to the housing (18).

2. An apparatus (10) as set forth in claim 1 wherein the housing (18) is formed and configured so as to be received into an aperture such that the temperature sensitive device (12) is in thermal communication with the interior of the aperture for sensing a temperature therein and such that each conductor (36) is exposed for electrical connection to circuitry external to the aperture.

3. An apparatus (10) as set forth in claim 2 wher in the housing (18) has a threaded exterior portion (48).

4. An apparatus (10) as set forth in claim 2 wherein the housing (18) has a smooth exterior portion (48).

5. An apparatus (10) as set forth in claim 1 wherein the housing (18) is formed of a material having the identified characteristics of polyehtersulphone.

6. An apparatus (10) as set forth in claim 4 wherein the housing is further composed of glass fibers.

7. An apparatus (10) as set forth in claim 5 wherein the housing is composed of between 20 and 45 percent glass fibers.

8. An apparatus (10) as set forth in claim 1 wherein the temperature sensitive device (12) includes a thermistor (14).

9. An apparatus (10) as set forth in claim 1 wherein the temperature sensitive device (12) includes a negative thermal coefficient device.

10. An apparatus as set forth in claim 1 wherein the temperature sensitive device (12) includes a positive thermal coefficient device.

11. An apparatus as set forth in claim 1 wherein the temperature sensitive device (12) and conditioning circuit (16) are surface mounted on a circuit board (17).

12. An apparatus (10) as set forth in claim 11 wherein said housing includes a main body portion (20), a cap portion (22) and a compression grommet (32), the main body portion (20) having an internal cavity portion (24) being adapted to receive the circuit board (817), conditioning circuit (16) and temperature sensitive device (12), the compression grommet (32) being adapted for insertion into the cavity portion (24) behind the circuit board (17) and including conductor apertures through which the conductors (31,36,38) pass, and the cap portion (20) being bonded to the main body portion (20) and adapted to hold the compression grommet (32) in place with sufficient compression to form seal against moisture infiltration through the conductor apertures and between the grommet (32) and the main body portion (20).

13. An apparatus (10) as set forth in claim 12 wherein the cap and main body portions (22,20) are bonded together by ultrasonic welding.

14. An apparatus (10) as set forth in claim 13 wherein the cap and main body portions (22,20) are bonded together using epoxy.

15. A temperature sensing apparatus (10), comprising:

a temperature sensitive device (12) having an resistance which varies with temperature;

a conditioning circuit (16) being electrically connected to the temperature sensitive device (12) and adapted to measure a resistance across the device (12) and producing a pulse-width-modulated

signal having a constant frequency and a duty cycle responsive to the sensed resistance;

a non-metallic, liquid resistant and thermally conductive housing (18) encapsulating the temperature sensitive device (12) and the electrical circuit (16); and

at least one electrical conductor (38) connected to the conditioning circuit (16) and being adapted to transmit the signal output from the electrical circuit, the conductor (38) extending through the housing (18) for electrical connection to circuitry external to the housing (18).

16. An apparatus (10) as set forth in claim 14 wherein the housing (18) is formed and configured so as to be received into an aperture such that the temperature sensitive device (12) is in thermal communication with the interior of the aperture for sensing a temperature therein and such that each conductor (36) is exposed for electrical connection to circuitry external to the aperture.

17. An apparatus (10) as set forth in claim 16 wherein the housing (18) has a threaded exterior portion (48).

18. An apparatus (10) as set forth in claim 16 wherein the housing (18) has a smooth exterior portion.

19. An apparatus (10) as set forth in claim 15 wherein the housing (18) is formed of a material having the identified characteristics of polyehtersulphone.

20. An apparatus (10) as set forth in claim 19 wherein the housing is further composed of glass fibers.

21. An apparatus (10) as set forth in claim 21 wherein the housing is composed of between 20 and 45 percent glass fibers.

22. An apparatus (10) as set forth in claim 15 wherein the temperature sensitive device (12) includes a thermistor.

23. An apparatus as set forth in claim 15 wherein the temperature sensitive device (12) includes a negative thermal coefficient device.

24. An apparatus as set forth in claim 15 wherein the temperature sensitive device (12) includes a positive thermal coefficient device.

25. An apparatus as set forth in claim 15 wherein the temperature sensitive device (12) and conditioning circuit (16) are surface mounted on a circuit board (17).

26. An apparatus as set forth in claim 25 wherein said housing includes a main portion, a cap portion and a compression grommet, the main body portion having an internal cavity portion adapted to receive the circuit board, conditioning circuit and temperature sensitive device, the compression grommet being adapted for insertion into the cavity portion behind the circuit board and including conductor apertures through which the conductors pass, and the cap portion being bonded to the main body portion and

adapted to hold the compression grommet in place with sufficient compression to form seal against moisture infiltration through the conductor apertures and between the grommet and main body portion.

27. A method of manufacturing a temperature sensing apparatus (10), comprising the steps of:

mounting a temperature sensitive device (12) on a circuit board (17), the temperature sensitive device (12) having a resistance which varies with temperature;

mounting conditioning circuit (16) on the circuit board (17), the conditioning circuit (16) being electrically connected to the temperature sensitive device (12) and adapted to sense the resistance of the temperature sensitive device (12) and produce and electrical signal which is insensitive to external resistive loads and has a magnitude responsive to the sensed resistance;

injection molding a housing (18) from non-metallic liquid resistant and thermally conductive material, the housing (18) having an internal cavity portion (24) adapted to receiving the circuit board (17);

connecting at least one electrical conductor (38) to the conditioning circuit (17), the conductor (38) being adapted to transmit the conditioning circuit output signal to circuitry external to the housing (18);

injecting a predetermined amount of encapsulant (30) into the internal cavity portion (24);

inserting the circuit board (17) into the internal cavity portion (24); and

sealing the internal cavity portion (24) to isolate the circuit board (17) fr m the atmosphere.

28. An apparatus as set forth in claim 27 wherein the conditioning circuit (17) is adapted to produce a pulse-width-modulated signal having a constant frequency and a duty cycle responsive to the sensed resistance.

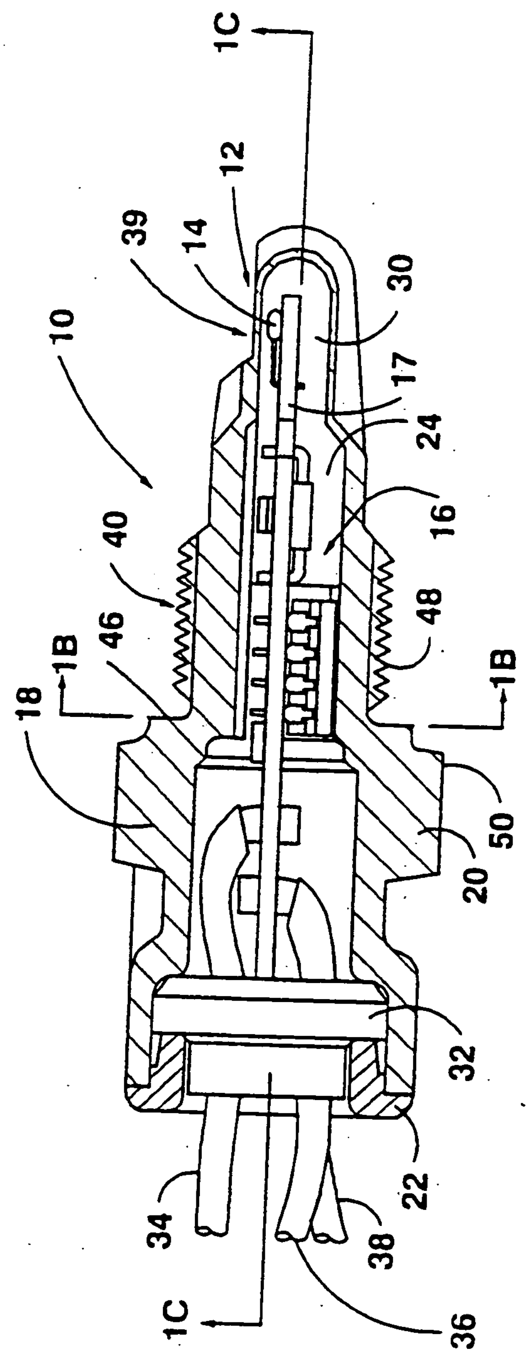


Fig_1A_

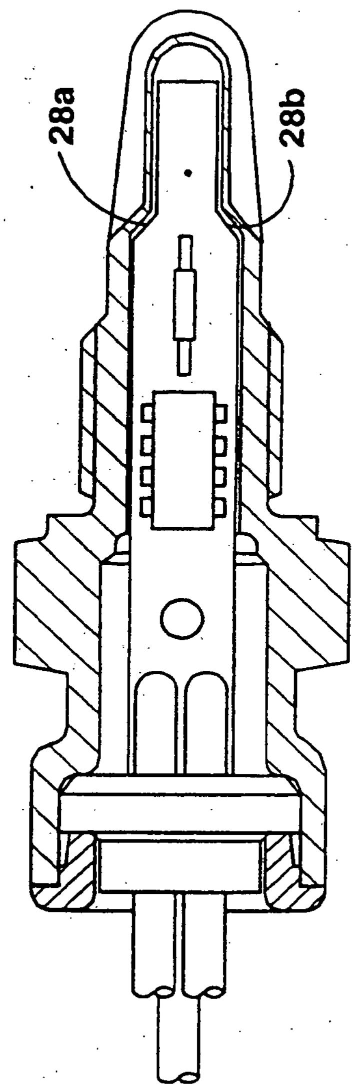


Fig_1C

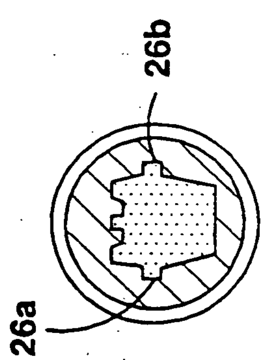


Fig_1B

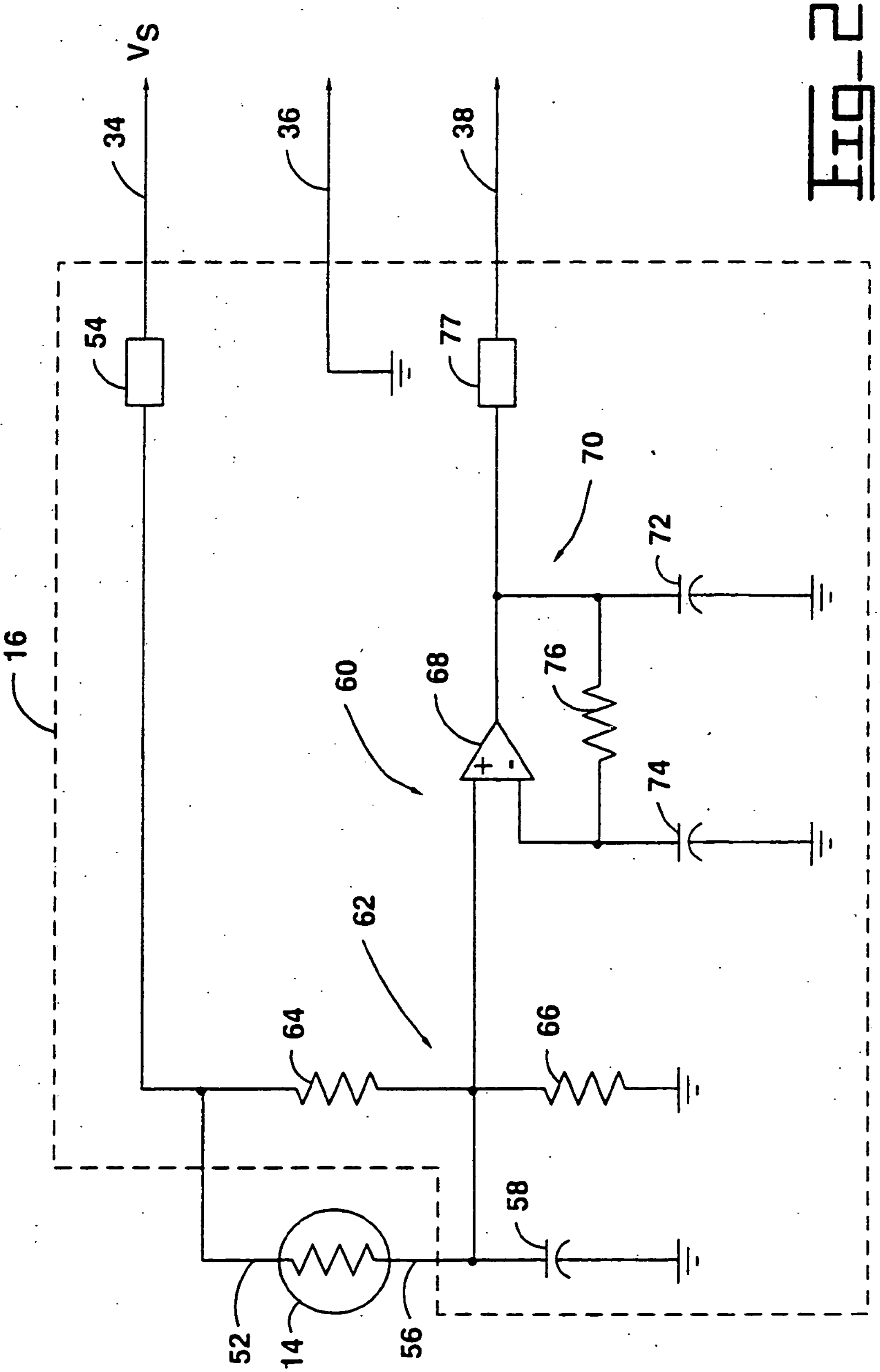
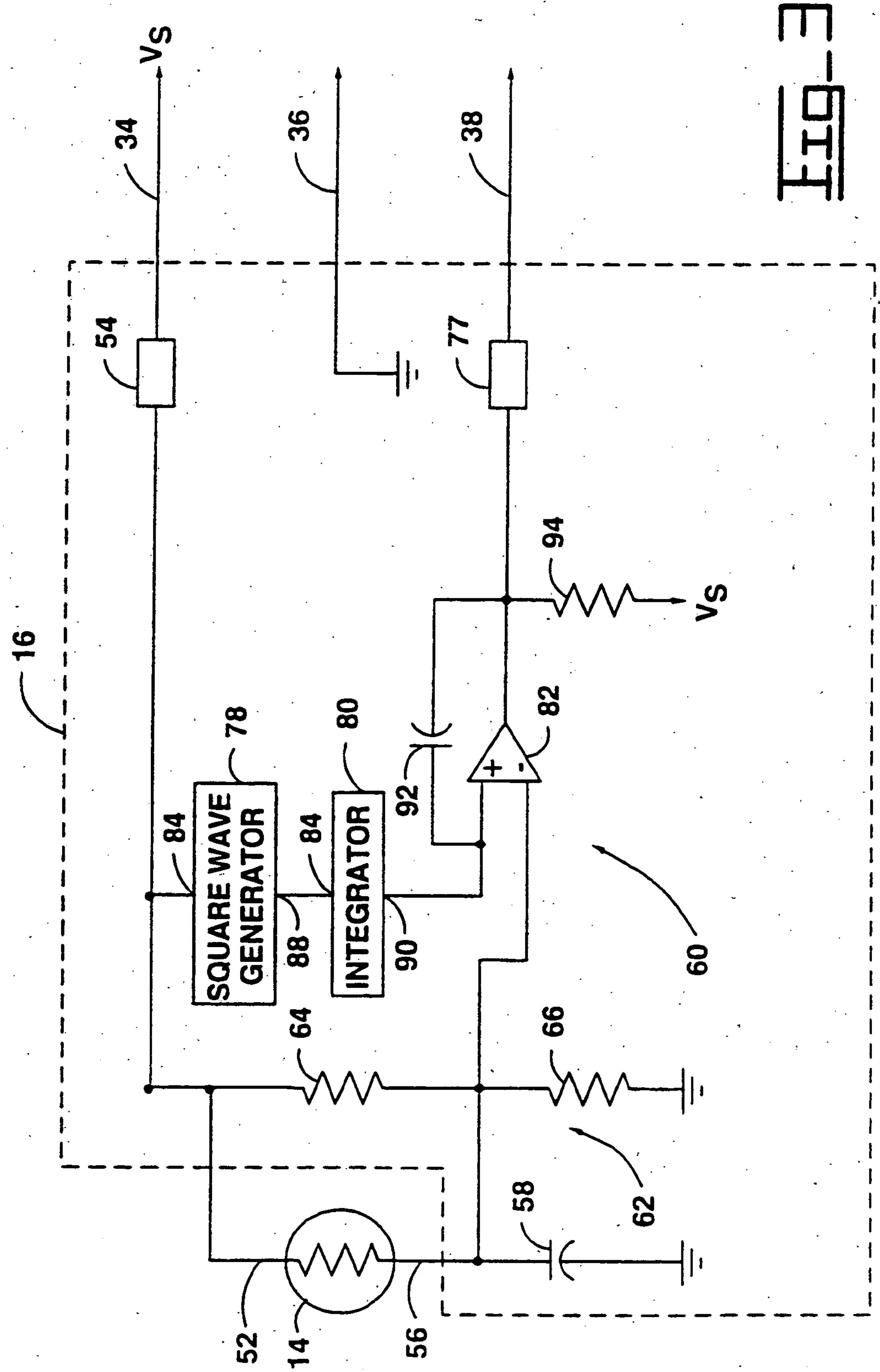


Fig 2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92
82
84
SQUARE WAVE GENERATOR
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88
INTEGRATOR
90
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64
66
62
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52
14
56

FIG. 3

INTERNATIONAL SEARCH REPORT

International Application No PCT/US 91/07954

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)[6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl. 5 G01K1/08

II. FIELDS SEARCHED

Minimum Documentation Searched[7]

Classification System	Classification Symbols
Int.Cl. 5	G01K

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched[8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT[9]

Category °	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No.[13]
A	EP,A,0 064 798 (ELMWOOD SENSORS LTD) 17 November 1982 cited in the application see the whole document ---	1
A	DE,U,8 704 350 (E.KUHNERT) 21 July 1988 see page 4, paragraph 4 - page 5 ---	1,11,12,27
A	DE,U,8 700 646 (KUNZER) 10 September 1987 see page 3 ---	1,3,5
A	GB,A,2 083 231 (ELMWOOD) 17 March 1982 see page 2, right column, line 98 - line 101 ---	1-3,8,9
	-/--	

° Special categories of cited documents : [10]

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"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
03 JUNE 1992	15.06.92.
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	RAMBOER P.

1

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category°	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
A	WORLD PATENTS INDEX LATEST Week 8109, Derwent Publications Ltd., London, GB; AN 81-B8617D & SU,A,742 724 (SKRIPNIK) 26 June 1980 see abstract see abstract ---	15
A	US,A,4 881 055 (INGERSOLL RAND CO) 14 November 1989 see abstract ---	5

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO. US 9107954 SA 56739

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on 03/06/92
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Patent document cited in search report	Publication date	Patent family member(s)		Publication date
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		FR-A-	2638838	11-05-90
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		JP-A-	2173535	05-07-90

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